EXACT SOLUTIONS FOR VEHICLE ROUTING AND SCHEDULING PROBLEMS WITH FULL SOFT TIME WINDOWS USING COLUMN GENERATION AND LABELING ALGORITHMS

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PREFACE

This thesis consists of several research works, which have been contributed to journal and conference papers as follows.

Journal Papers

Bhusiri, N., Qureshi, A.G. and Taniguchi, E. (2013) Vehicle routing and scheduling problem for convenience store industry considering soft time windows. *Proceedings of the 10th EASTS Conference* (To be presented during September 9-12, 2013, Taiwan and to be published online via *Journal of the Eastern Asia Society for Transportation Studies* in 2014).

Bhusiri, N., Qureshi, A.G. and Taniguchi, E. (2013) Application of Just-In-Time concept in urban freight transport. *Proceedings of the 8th International Conference on City Logistics* (To be presented during June 17-19, 2013, Bali, Indonesia and to be published online via Procedia Social and Behavioral Sciences in 2014).

Bhusiri, N., Qureshi, A.G. and Taniguchi, E. (2012) Full soft time window constraints on routing problem by considering the trade-off between fixed vehicle costs and time-dependent arrival penalties. *Transportation Research Part E* (under the second revision process; submitted on October 3, 2012 and received the first review on February 7, 2013).

Full Paper as Peer-reviewed Proceedings

Qureshi, A.G., Bhusiri, N. and Taniguchi, E. (2012) Relaxing time window constraints on vehicle routing problem. *Proceedings of the 4th International Conference on Transportation and Logistics; T-LOG,* August 23-25, 2012, Busan, Korea.

Conference Papers

Bhusiri, N., Taniguchi, E. and Qureshi, A.G. (2011) Column generation with bi-directional dynamic programming for vehicle routing and scheduling problem with semi-soft time windows. *Proceedings of the 44th Conference on Infrastructure Planning*, November 25-27, 2011, Gifu, Japan.

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ABSTRACT

Urban freight transport (UFT) generally deals with the mobility of merchandises, products, materials, used items, and waste. UFT is a vital component in urban management systems, where its usage would provide convenience to people and also provide the growth to urban areas. Since the globalization age has emerged, UFT has become increasingly important and demand of UFT in response to various needs of people has considerably been higher and higher. However, there have also been various serious problems associated with the growth of UFT. One particular scheme, which attempts to cope with UFT related problems, is called city logistics. In general, city logistics consists of several measures and initiatives for alleviating the effects of UFT related problems and also enhancing the efficiency of UFT operation. One of the most commonly studied city logistics measures is route optimization.

Among route optimization initiative, this thesis has focused on the vehicle routing problem (VRP) in general and the VRP under time window constraints in particular. The vehicle routing problem with hard time windows (VRPHTW) has been among the first variant of the VRP under time window constraints appeared in literature. The VRPHTW has become widespread since its application has played a central role in response to customer needs in the globalization age. However, it has been found that the VRPHTW lacked practicalities to some extent. Later, the second variant of the VRP under time window constraints has been launched to the literature. Such variant has been called the vehicle routing problem with semi-soft time windows (VRPSSTW). Nevertheless, the VRPSSTW could overcome the drawbacks of the VRPHTW, yet partially. Both the VRPHTW and the VRPSSTW still generated a significant amount of waiting time of delivery vehicles. Such waiting time of vehicles is meaningful in practice in which it might cause additional expenses and some traffic-environmental related problems

Behind the reasons above, in addition to minimization of overall routing costs, this thesis has also attempted to optimize total waiting time of vehicles. The highlighting problem here has been addressed as the vehicle routing problem with soft time windows (VRPSTW). A few VRPSTW papers have been introduced to literature, yet all of those have differently been defined from the VRPSTW proposed in this thesis. Consequently, a mixed integer formulation has newly been developed for the VRPSTW based on the new soft time window

characteristics. Three particular decision variables were composed of in the VRPSTW model, and they must optimally be processed. In addition to travel costs, the time-dependent arrival penalties (in case of both early and late arrival) and fixed vehicle costs were also included to the objective function of the VRPSTW model. Both time-dependent arrival penalties and fixed vehicle utilization costs were of importance in the VRPSTW characteristics.

The branch-and-price exact-based approach has first been employed to solve the VRPSTW to optimality. The structure of the branch-and-price approach is to embed column generation algorithm into the branch-and-bound scheme. Decomposition technique of column generation onto the VRPSTW model resulted in the set partitioning restricted master problem and its new subproblem, namely the elementary shortest path problem with resource constraints and time-dependent arrival penalties (ESPPRC-TAP). Particularly focusing on the ESPPRC-TAP, some complexities received directly from the VRPSTW model might be concerned. As the proposed VRPSTW differs in definition, use of the existing subproblem solution algorithms is not applicable for the ESPPRC-TAP. Therefore, four new subproblem solution techniques have been developed including the 1-SA, the 2-SA, the Heu-1&Heu-2&1-SA, and the Heu-1&Heu-2&2-SA. The branch-and-price approach with the 1-SA technique was of low efficiency, while use of the 2-SA technique was more advantageous due to involving less number of labels generated. Furthermore, when incorporating these two techniques with the newly developed heuristic-based algorithms, their performances were much better. Finally it was found that the branch-and-price approach with the 2-SA along with heuristic-based algorithms (the resulting Heu-1&Heu-2&2-SA technique) has been among the best technique.

Since the VRPSTW has been known to be NP-hard problem, the metaheuristic-based genetic algorithm (GA) has also been developed in this thesis, providing the (nearly) optimal solution to the VRPSTW. The proposed GA has employed several significant genetic operators found in the literature. In particular, for more advanced exploration of the solution space, the GA has also taken into consideration a newly advanced search strategy, which has been called the intermediate infeasible search. Based on performance evaluation of the GA and the branch-and-price approach performed on small-sized and medium-sized VRPSTW instances, it could be said that the proposed GA worked well with minor tolerance. It might be noted that the GA was more favorable when tackling larger or more complex instances, which might exceed the capability limit of the branch-and-price approach. However, the branch-and-price approach was still inevitable as it could guarantee the exactness of solutions obtained, whereas all other solution approaches such as the GA could not even just express how close to the optimal solutions their solutions were.

The comparisons among three variants of the VRP under time window constraints have also further been conducted. It was observed that by accepting late deliveries with late arrival penalties (i.e. occurred in the VRPSSTW and the VRPSTW), the number of vehicles used in the operation could be saved. Consequently, fixed vehicle costs, which were very high values, could be reduced, thus leading also to decrease in overall costs. On the other hand, by taking early arrival penalties or waiting costs into account (i.e. occurred in the VRPSTW), the total amount of waiting time was dramatically decreased. It was also found that these penalties (both early and late) occurred in the VRPSTW contributed only small fractions to the optimal solution costs. In addition, firm’s resources, e.g. vehicle and labor, were better utilized due to such penalties. Finally, in the perspectives of cost, waiting time, and resource utilization, the VRPSTW outperformed the VRPHTW and the VRPSSTW.

The proposed soft time window definition presented in this thesis have also been applied to a class of distribution and routing systems of franchising convenience store chain. The concerned problem could then be addressed as the vehicle routing problem with soft time windows and simultaneous pickups and deliveries (VRPSTWSPD). Since all service vehicles have to perform pickup services and delivery services simultaneously at each visit, the VRPSTWSPD might particularly be concerned with additional complexity due to the non-monotonousness of loading flow along the route. The VRPSTWSPD has been also a novel variant in the VRP literature and has been known to be NP-hard problem as well. The mixed integer programming model of the VRPSTWSPD has also been developed in this thesis, where it has been generalized from the proposed VRPSTW model. Both the branch-and-price approach and the GA have been employed for solving the VRPSTWSPD; yet they have particularly been extended to cope with non-monotonousness of loading flow. Both solution approaches performed well on small-sized and medium-sized VRPSTWSPD instances, whereas the GA generated slightly higher solution costs in comparison to the branch-and-price approach. However, the GA was of advantages over the branch-and-price approach when tackling large-sized instances and practical instances.

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LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
B2B	Business-to-Business Transactions
CDS	Cooperative Delivery System
CVRP	Capacitated Vehicle Routing Problem
DTSP	Dynamic Travelling Salesman Problem
ESPPRC	Elementary Shortest Path Problem with Resource Constraints
ESPPRC-TAP	Elementary Shortest Path Problem with Resource Constraints and Time-dependent Arrival Penalties
ESPPRCLAP	Elementary Shortest Path Problem with Resource Constraints and Late Arrival Penalties
FLP	Facility Location Problem
GA	Genetic Algorithm
JIT	Just-In-Time
kg	Kilogram
LRP	Location Routing Problem
m-TSP	Multiple Travelling Salesman Problem
MDVRP	Multi-depot Vehicle Routing Problem
MP	Master Problem
NP-Hard	Non-Deterministic Polynomial-Time Hard
PFIH	Push Forward Insertion Heuristics
RMP	Restricted Master Problem
SP	Subproblem
SPPRC	(Non-Elementary) Shortest Path Problem with Resource Constraints
TS	Tabu Search
TSP	Travelling Salesman Problem
TSPTW	Travelling Salesman Problem with Time Windows
TW	Time Windows
UFT	Urban Freight Transport
VRP	Vehicle Routing Problem
VRPB	Vehicle Routing Problem with Backhauls

LIST OF ABBREVIATIONS (CONT.)

VRPDP	Vehicle Routing Problem with Delivery and Pickup
VRPHTW	Vehicle Routing Problem with Hard Time Windows
VRPPD	Vehicle Routing Problem with Pickup and Delivery
VRPSPD	Vehicle Routing Problem with Simultaneous Pickup and Delivery
VRPSSTW	Vehicle Routing Problem with Semi-Soft Time Windows
VRPSTW	Vehicle Routing Problem with Soft Time Windows
VRPSTWSPD	Vehicle Routing Problem with Soft Time Windows and Simultaneous Pickup and Delivery